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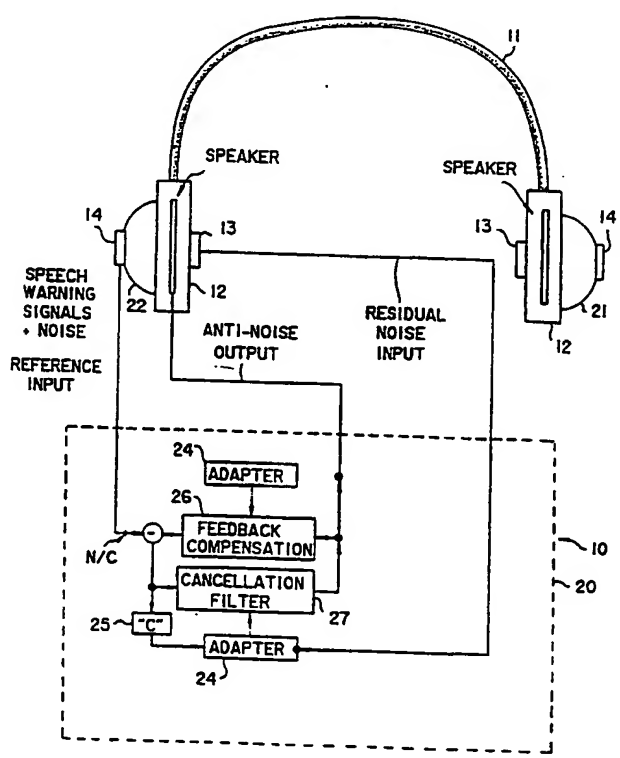
(54) Title: ACTIVE PLUS SELECTIVE HEADSET

(57) Abstract

An active plus selective headset system for provision of active attenuation of broadband noise as well as speech filtering comprising a headset (11) with reference microphones (14), residual microphones (13) and speakers (12) on each of a pair of open backed muffs (21, 22) and a controller (20).



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ACTIVE PLUS SELECTIVE HEADSET

This invention relates to a headset for actively canceling unwanted noise while selectively allowing necessary speech to reach the user's ear.

In the past, attempts to combine the two protections i.e., high and low frequency attenuation, has resulted in not only the noise being attenuated but also the speech that the wearer needs to hear. Some systems met only limited success with fixed or "near-stationary" noise but not with the other noise of either (a) varying spectral characteristics or (b) brief duration noises with "spikes". Examples of such a system is found in U.S. Patent No. 4,025,721, to Graupe et al and U.S. Patent 4,185,168 to Graupe et al. Other systems like that found in U.S. Patent No. 4,455,675 to Bose actively attenuate all sounds at low frequencies and passively attenuate all high frequency sounds. These sounds include speech and warning signals that want to be heard by the person wearing the headset.

The instant invention solves the problem now existant, that of <u>total</u> attenuation of the noise and speech, by providing a solution of an active headset that can employ any of several selective algorithms such as those disclosed in U.S. Patent No. 4,654,871 to Chaplin, hereby incorporated by reference herein. Alternatively, it can employ the algorithm disclosed in U.S. Patent No. 5,105,377 to Ziegler which is also incorporated herein by reference. In addition it can employ other algorithms such as that disclosed in the application of <u>Ziegler in U.S. Patent Application No. 07/421 759 which is hereby incorporated by reference</u> herein.

In applications for noise canceling headsets, particularly in industrial environments, attenuation of low frequency noise as well as noise that covers the speech band (300 to 3300 Hz) passive hearing protection works extremely well at higher frequencies (typically above 1000 Hz) whereas active noise cancellation has been shown to achieve similar levels of protection at lower frequencies (50 to 1000 Hz). Passive, however, also attenuates speech and warning signals and the protectors are uncomfortable to wear. This invention provides a solution that <u>simultaneously</u>

provides the protection offered by a passive headset in a lightweight open back headset while using active adaptive feed forward control algorithms that attenuate all sounds in the 20 to 3300 Hz frequency band. Additionally, adaptive speech filtering or in-wire control technology separates speech from noise and passes the speech to the user.

Accordingly it is an object of this invention to provide an active noise canceling headset with selectivity.

Another object of this invention is the provision of an open back muff headset with selective filtering.

These and other objects of this invention where reference is had to the accompanying drawings in which

Fig. 1 shows a typical active/passive headset system incorporating the instant invention.

Fig. 2 shows an active plus selective headset system with an open back muff that incorporates active control and adaptive speech filtering to allow speech to pass with the "anti-noise" signal.

Fig. 3 shows a more detailed description of the active control system of Figure 2.

Fig. 4 shows a more detailed description of the adaptive speech filtering technique to be used in this headset design.

In Fig. 1 there is shown an active/passive closed back headset system 10. It consists of a typical passive headset 11, loudspeakers 12 that drive the anti-noise and residual microphones 13 to sense any remaining noise near the ear and reference microphones 14 to send advanced information for feed forward approaches and a system controller 20 which synthesizes the anti-noise signal.

The headset shown has closed backs 21, 22 for passive attenuation without the speakers, microphones and system controller, this headset would be a typical passive hearing protector.

The system is designed to use various algorithms such as that of Ziegler in U.S. Patent 5,105,377 or an adaptive feed forward approach. Both these algorithms use a

reference signal as inputs. The digital virtual earth (DVE) algorithm develops a reference signal by subtracting an equalized version of its own anti-noise signal from the residual signal. The adaptive feed forward uses the reference microphone as its input and is very effective on complicated noise environments that are broadband and random in character. The Least Means Square (LMS) adapter 24 shown in Fig. 1 are Filtered - X versions which have inherent compensation for the effects of the feedback delays around the loop. Box "C" at 25 is the impulse response of active cancellation system.

Feedback compensator 26 and cancellation filter 27 complete the component portions of the controller.

DVE is highly effective to use in simple noise environments having only a few harmonics even where the noise varies tremendously. It has also been demonstrated to be very effective doing broadband cancellation at low frequencies (50 - 700 Hz).

Speakers 12 of the headset are large enough to be capable of producing anti-noise at the same level as the noise to be canceled. They have little or no distortion and have a minimum of input-to-output delay as any delay in the feedback loop slows down the system adaptation rate.

Residual microphones 13 are typically small electret microphones mounted on the speaker frame near the ear. It must faithfully reproduce the sound that remains at the ear after cancellation so that the controller can make further adjustments to the anti-noise signal.

Reference microphones 14 are small electret microphones attached to the outside of the headset at a distance from the ear canal. This reference microphone is used to provide advanced information about the noise. The higher the frequency of the noise the more advanced information is needed to effectively cancel the noise.

Fig. 2 shows an active plus selective headset system 50 with headset 51 having open backed muff positions 52, reference microphones 53, speakers 54 and residual microphones 55. An earplug (not shown) may be substituted for the open backed muff.

The active /passive system 10 previously described can be configured to actively attenuate all sounds in the frequency band from 20 to 3300 Hz without the need for a passive muff or earplug. The approach uses an adaptive feed forward control algorithm to actively attenuate the damaging noise in this band. In order to accomplish this it is necessary to minimize the delays of the digital signal processing system, which include delays introduced by the anti-aliasing and reconstruction filters shown in Figure 3 and the acoustic delay of the speaker and residual microphone physical system, in order to effectively attenuate noise at the higher frequencies.

The controller 60 has adapters 61,62, feedback compensation 63, cancellation filter 64 and adaptive speech filter 65. Controller 60 uses a parallel adaptive speech filtering technique to pass speech to the user. Adaptive speech filtering techniques can be employed to work with the particular noisy environment. The active controller attenuates noise in the band of interest and allows speech and warning signals to pass via the adaptive speech filtering path which incorporates a warning signal filter as shown in Fig. 2. It is similar to the active/passive system except for the open backed headset design and the addition of a parallel adaptive speech filtering path and warning signal filter path as integral parts of the controller. The input to the speech filter and controller are the upstream reference microphones 53.

This reference microphone contains noise and speech. The speech is filtered from the noise and passed with the "anti-noise" generated from the adaptive feed forward controller and sent to the headset loud speaker. Both speech and warning signals, which are typically above the speech band and of known frequencies, will be heard by the user of the lightweight and open back headset.

With reference to Figure 2, the "anti-noise" and speech output signals are mixed and input to the speakers. This combined signal output sample, u_k, is given by

$$\underline{x}_k = \underline{r}_k - \underline{z}_k$$

$$y_k = \underline{A}_k \underline{s}_k$$

$$u_k = w_k + y_k$$

	u_k	is the output speech and anti-noise value
where	$\underline{r}_k$	is a vector of the most recent examples of the residual signal
	$\underline{z}_k$	is a vector of the output of the speech filter after it passed through the impulse response $\underline{C}_k$
	$\underline{A}_k$	is a vector of cancellation filter coefficients
	y_k	is the output anti-noise value
	w_k	is the output speech value.
	$\underline{s}_k$	is the vector of compensated inputs.

Inputs to the controller and speech filter are the reference signal, v_k, and residual signal r_k that are picked up via the reference sensor and residual sensor respectively. The adaptive feedforward controller generates an "anti-noise", y_k, and the adaptive speech filter generates a clean speech signal, w_k, that are mixed to form the output signal u_k which is sent to the speakers. Each ear piece operates independently with separate reference and residual sensors and actuator.

It is essential that the output of the speech filter, w_k, be filtered through the system in pulse response, $\underline{C}_k$, and subtracted from the residual input, r_k, so as not to interfere with the operation of the adaptive feedforward controller. Otherwise, the controller will attempt to adapt to and cancel the speech signal that is output to the speaker.

Several techniques can be used to minimize the delays of the system. First, passive material can effectively act as a low pass filter for the input reference and residual sensors. This would eliminate the need for anti-aliasing filters and thus the delays introduced by these filters would be eliminated. This technique has been shown to be quite effective in the active control of noise in ducts using the adaptive feedforward controller.

Another technique removes neither the anti-aliasing filters nor the reconstruction filters but essentially by-passes the delays introduced by these filters by inserting an analog zero'th order tap. This is achieved by placing an amplifier between

the output of the incoming gain control and the output of the reconstruction filters shown in Figure 3.

A final technique, which will be even more effective as the speed of microprocessor technology increases, is to sample at a rate of 40 kHz or greater, this eliminates the need for anti-aliasing and reconstruction filters because the cut off frequency of 20 kHz is at the limit of the loudspeaker response.

CLAIMS

1. An active plus selective headset system which provides active broadband attenuation of noise as well as speech filtering, said system comprising

a headset means adapted to be worn by a user,

reference sensing means on said headset means adapted to sense speech, noise and warning signals,

speaker means on said headset means adapted to convey speech and warning signals to the user, and

controller means adapted to provide active broadband attenuation of noise as well as speech filtering so that only the warning signals and speech reach the ear.

2. A system as in claim 1 wherein said headset means includes residual microphone means located on said headset means and including a feedback means connected to said speaker means.

3. A system as in claim 2 wherein said feedback means includes an adaptive speech filter means and a cancellation filter means.

4. A system as in claim 2 wherein said controller means is run by an adaptive feedforward algorithm.

5. A system as in claim 2 wherein said headset means includes an open backed muff.

6. A system as in claim 2 wherein said reference sensing means is an electret microphone.

7. A system as in claim 6 wherein said headset system comprises a pair of open backed muffs with the reference sensing means located on the outside of said muffs.

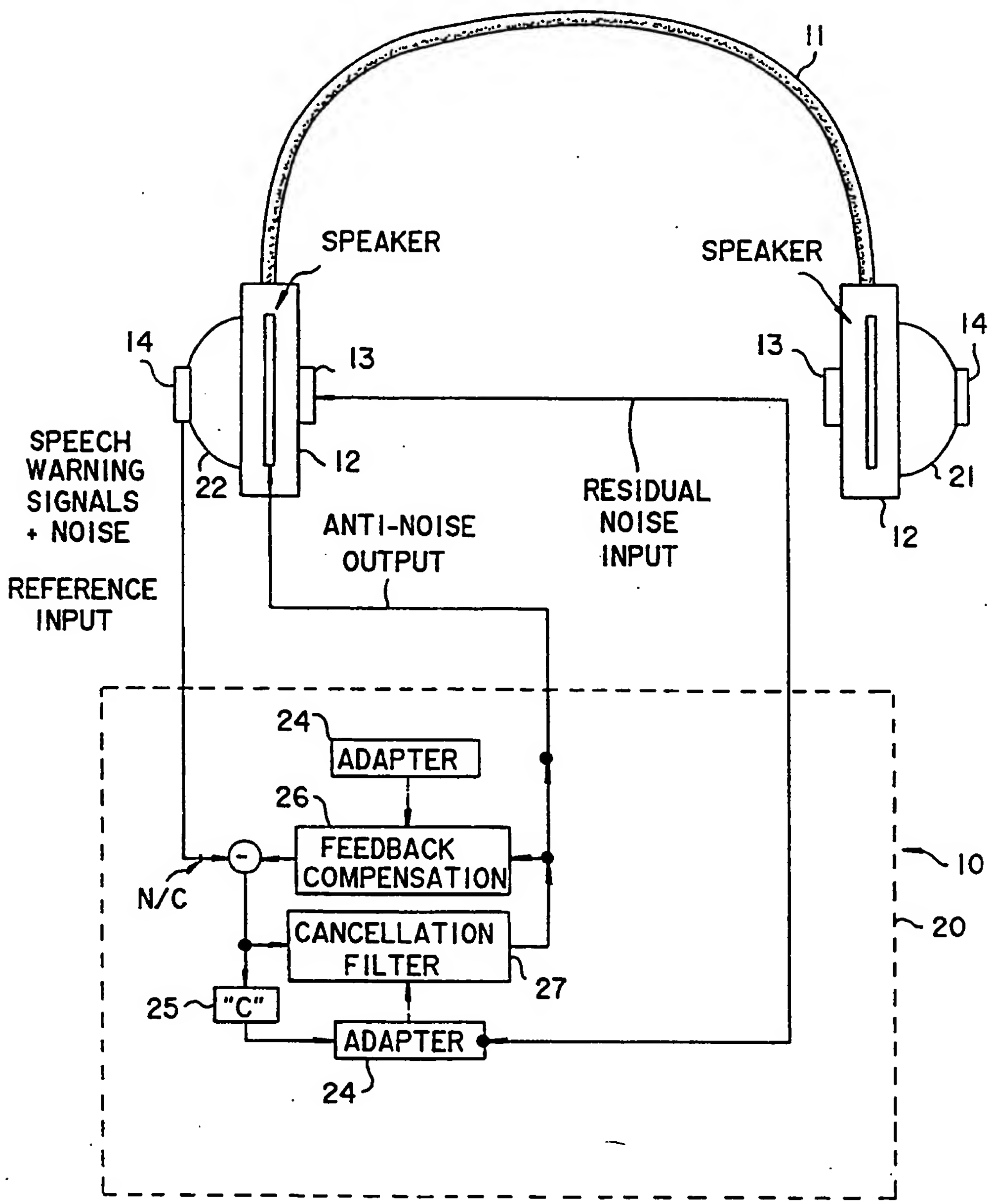
8. A system as in claim 1 wherein said adaptive speech filtering means adapted to filter speech from noise.

9. A system as in claim 1 wherein said adaptive speech filtering output is mixed with said controller output and resulting signal passed to speaker means.

10. A system as in claim 1 wherein said adaptive speech filtering output is filtered by the impulse response of the active cancellation system and subtracted from the residual microphone signal so as not to interfere with the operation of said controller.

11. A system as in claim 1 wherein said reference sensing means is external of speaker means on said headset means and said controller is adapted to employ a feedforward method of noise cancellation.

12. A system as in claim 1 wherein said reference sensing means is internal of said speaker means on said headset means and said controller is adapted to employ a feedback method of noise cancellation.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SPEAKER
SPEAKER
14
13
13
14
SPEECH
WARNING
SIGNALS
+ NOISE
22
12
21
12
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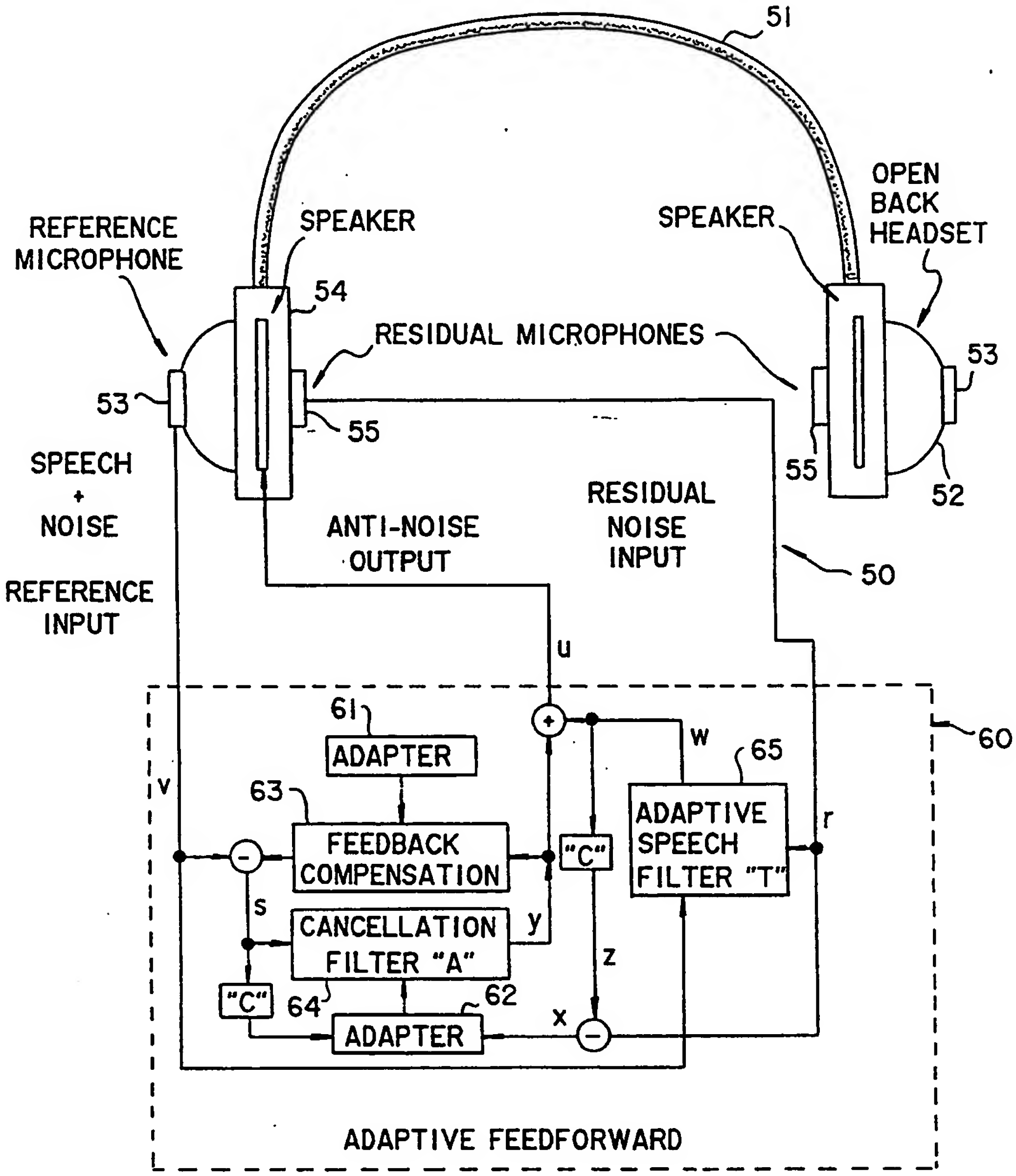
OUTPUT
RESIDUAL
NOISE
INPUT
REFERENCE
INPUT
24
ADAPTER
26
FEEDBACK
COMPENSATION
N/C
CANCELLATION
FILTER
27
25
"C"
ADAPTER
24
10
20

FIG.1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OPEN
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REFERENCE
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SPEAKER
SPEAKER
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RESIDUAL MICROPHONES
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SPEECH
+
NOISE
ANTI-NOISE
OUTPUT
RESIDUAL
NOISE
INPUT
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REFERENCE
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61
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ADAPTIVE
SPEECH
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"C"
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62
ADAPTER
x
ADAPTIVE FEEDFORWARD

FIG.2

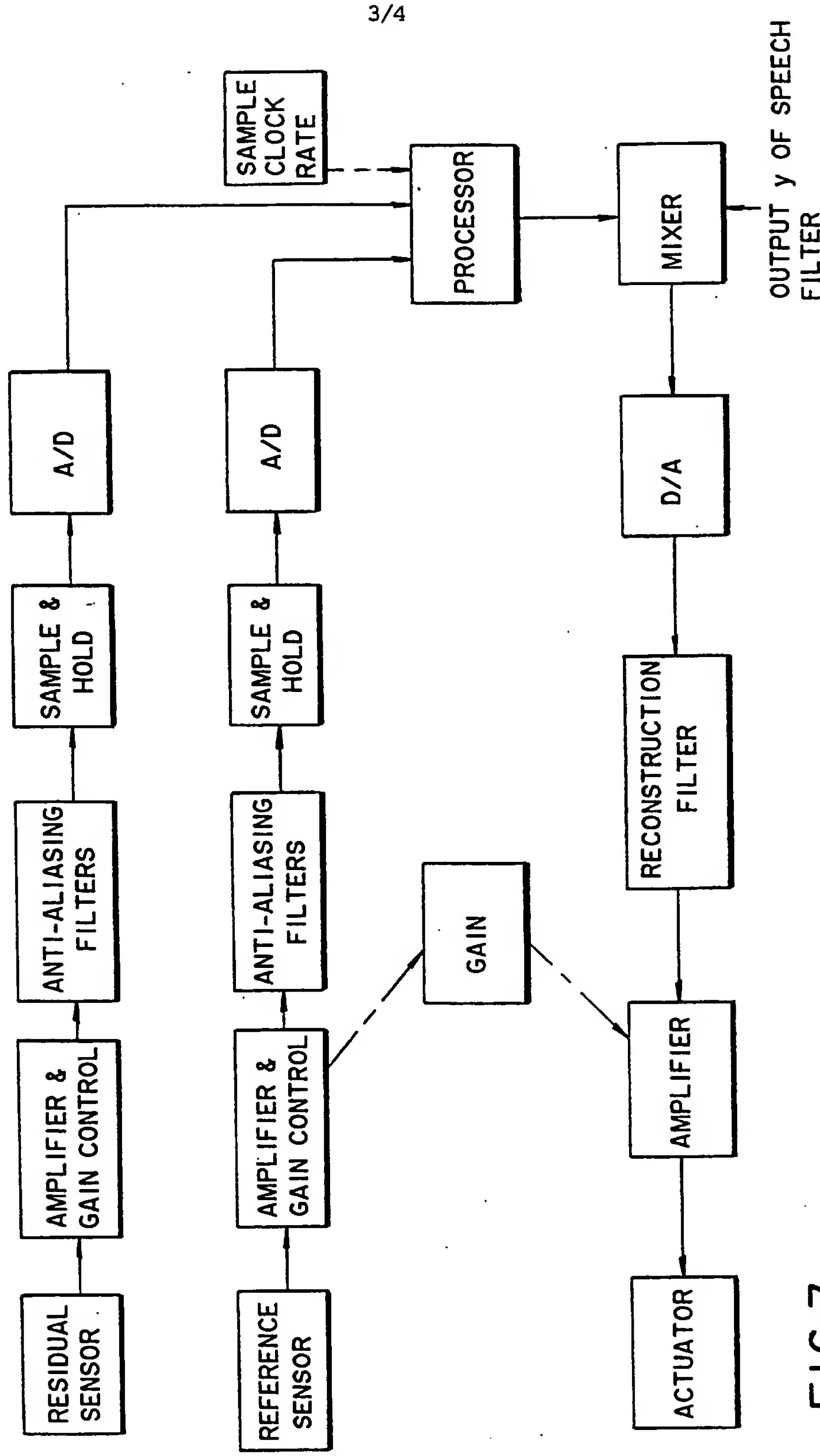
SAMPLE CLOCK RATE
PROCESSOR
MIXER
OUTPUT y OF SPEECH FILTER
A/D
A/D
D/A
SAMPLE & HOLD
SAMPLE & HOLD
RECONSTRUCTION FILTER
ANTI-ALIASING FILTERS
ANTI-ALIASING FILTERS
GAIN
AMPLIFIER & GAIN CONTROL
AMPLIFIER & GAIN CONTROL
AMPLIFIER
RESIDUAL SENSOR
REFERENCE SENSOR
ACTUATOR

FIG.3

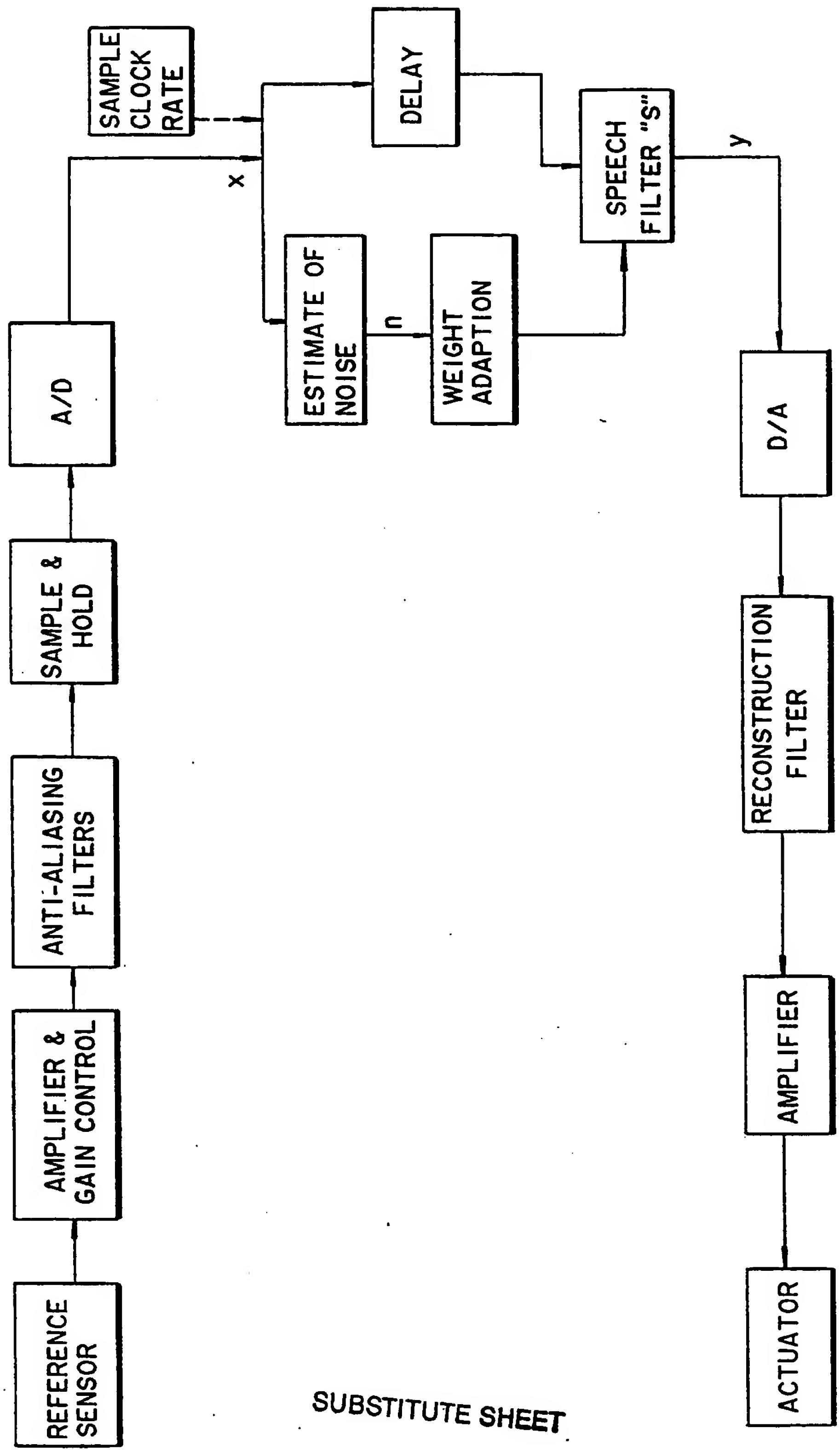
REFERENCE SENSOR
AMPLIFIER & GAIN CONTROL
ANTI-ALIASING FILTERS
SAMPLE & HOLD
A/D
SAMPLE CLOCK RATE
x
DELAY
ESTIMATE OF NOISE
n
WEIGHT ADAPTION
SPEECH FILTER "S"
y
D/A
RECONSTRUCTION FILTER
AMPLIFIER
ACTUATOR

FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/04567

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H03B 29/00
US CL :381/71
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 381/72,74

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US,A 3,952,158 (KYLE ET AL) 20 APRIL 1976 SEE FIGS. 1-5	1,8 2-7,9-12
Y	US,A 5,046,103 (WARNAKA ET AL) 03 SEPTEMBER 1991 SEE ABSTRACT AND FIGS. 1-2	2-7,9-12
Y	US,A 5,091,953 (TRETTER) 25 FEBRUARY 1992 SEE ABSTRACT AND FIGS. 1 AND 5	2-7,9-12
X Y	US,A 4,061,158 (FREIFELD) 06 DECEMBER 1977 SEE FIGS. 2-5	1-8 2-7,9-12
Y	US,A 4,064,362 (WILLIAMS) 20 DECEMBER 1977 SEE ABSTRACT AND FIG. 1	1,8
Y	US,A 4,953,217 (TWINEY ET AL) 28 AUGUST 1990 SEE ABSTRACT AND FIG. 1	2-7,9-12
A	US,A 4,677,678 (MCCATCHEN) 30 JUNE 1987 SEE ABSTRACT AND FIGS. 1-7	1-12

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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International application No.
PCT/US92/04567

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A 5,105,377 (ZIEGLER, JR.) 14 APRIL 1992 SEE ABSTRACT AND FIGS. 1-5	2-7, 9-12